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THE TRANSITION TO UNCONTROLLED CRUDE OIL PRICES

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I. INTRODUCTION

Except for a brief period in 1973, crude oil produced in the United States has been subject to price controls since August 1971. Since 1973 a multiple tier price control system, coupled with an ingenious administered market in rights to refine price controlled oil, has been developed in an attempt to reconcile the goals of minimizing the cost of petroleum products to consumers and of maintaining efficient resource allocation in crude oil production. In December 1975, Congress mandated the gradual removal of oil price controls -- an objective toward which only minimal progress has been made in the past two years.

If one takes a traditional approach to measuring the welfare costs and distributional effects of price controls, the current system fares rather well. In a subsequent section of this paper I will use a static model of crude oil supply and demand to estimate the welfare loss and the transfer of income from owners of petroleum resources to consumers of petroleum products that result from price controls. The admittedly crude results suggest strongly that the income transfer is considerably larger than the welfare loss. Several other authors, including Hall and Pindyck, Roush,

and Cox and Wright (1977) have used similar approaches, although the only comparable quantitative results are flawed by a failure to specify the structure of price controls in sufficient detail.

The static approach suffers from its inability to treat explicitly the effects of current oil production decisions on future production possibilities. At best these effects are incorporated through qualitative reference to concepts of "user cost" which have been developed in the literature on extraction of non-renewable resources.¹

A dynamic analysis of price controls would focus on the timing of extraction of a limited resource and on the relation between price expectations and current production decisions. Unfortunately, sophisticated theoretical analyses of non-renewable resources have tended to be conducted in terms of aggregate growth models, and investigations of the behavior of extractive industries under imposed price paths -- as opposed to the optimal paths found in the growth literature -- are, generally, lacking.²

The purpose of this paper is to outline some initial steps toward the construction of an adequate dynamic analysis of oil price controls. It is well-known that rising prices give an incentive to delay extraction of a non-renewable resource, the strength of which varies with the rate of price increases. Consequently comparison of marginal production costs and current prices -- the static approach -- cannot give an equally valid prediction of production rates under price ceilings that are constant over time and of production rates under rising world market prices.

A similar problem arises with respect to decontrol. If domestic prices are allowed to rise from their current ceilings to world prices, an incentive to delay production would result (as has been noted by all the authors mentioned). Evaluation of alternative paths to decontrol is possible only in a dynamic context.

The plan of this paper is as follows: first, a precise description of the goals and structure of current price controls is provided. Then those controls are characterized in a static model that generates estimates of efficiency losses and wealth transfers. In the final section, a simple dynamic model of oil production is developed. The greater data requirements of a dynamic model make it impossible to provide quantitative results comparable to those which come out of the static analysis. However, the dynamic model does lead to two qualitative conclusions different from the static analysis: 1) in the short term, continued controls are likely to lead to larger rates of domestic crude oil production than would exist if controls were removed and 2) a multi-part pricing system that is neutral in its effects on production decisions in a static context is not neutral in a dynamic setting.

II. THE GOALS AND STRUCTURE OF PRICE CONTROLS

The current structure of crude oil price controls has evolved from a system created by the Cost of Living Council (CLC) in August 1973. The CLC system took effect during a period of rising oil prices, but before the rapid escalation of oil prices in the world market that followed the oil embargo of 1973. Congressional action and administrative rulemaking combined to shape the evolution of price controls.

In August 1973 the Cost of Living Council created a two-tier price system for all domestic crude oil. Imported crude oil was exempt from controls. "Old" oil was defined as oil produced from a property -- then roughly the same as a lease tract -- in quantities less than 1972 production levels on that property. The price of old oil was set at the posted price in effect at that field on May 15, 1973, plus \$1.35 per barrel. That rule resulted in an average price of old oil of about \$5.00 per barrel.

Crude oil produced in excess of 1972 production levels from the same property ("new oil") and oil from properties that averaged less than 10 barrels per well per day was exempt from controls. In addition, each barrel of new oil produced "released" one barrel of old oil from controls. By December 1975, uncontrolled oil was selling at a price of about \$13 per barrel. Because of "released" oil, the additional revenue generated by producing a barrel of new oil was about \$21 -- the price of new oil plus the increase in the price at which old oil could be sold.

In October 1973, the Organization of Arab Petroleum Exporting Countries (OAPEC) announced a reduction of crude oil supplies to countries supporting Israel, cutting off about one-third of U.S. oil imports at the height of the embargo. On November 27, 1973, Congress enacted the Emergency Petroleum Allocation Act of 1973 (EPAA), which directed the President to "promulgate a regulation for the mandatory allocation of crude oil, residual fuel oil, and each refined petroleum product ... and at prices specified in ... such regulation."³

The legislative history of EPAA makes it clear that the primary purpose of the act was to create an allocation program designed to alleviate the effect of petroleum shortages created by the embargo. Price controls were authorized as an adjunct to the allocation program. The conferees stated that pricing authority was "included on the premise that it does no good to require the allocation of products if sellers are then permitted to demand unfair and unrealistic prices."⁴ They continued that "reference to equitable prices is specifically intended to emphasize that one of the objectives of the mandatory allocation program is to prevent price gouging or price discrimination which might otherwise occur on the basis of current shortages."⁵ Those price controls also had the clear purpose of preventing windfall profits to energy producers that would result from domestic oil prices rising to the price of imported oil, and of transferring those potential profits into the hands of consumers as low energy prices. Coping with inflation was not mentioned as a purpose of price controls.

Terse mention was made of "economic efficiency" and "minimization of economic distortion, inflexibility, and unnecessary interference with market mechanism" as objectives of the price control and allocation program.⁶

The system of crude oil price controls created by the CLC was continued under the authority granted by the EPAA. Consequently crude oil price controls continued after termination of the Economic Stabilization Program removed price controls from other sectors of the economy.

The price control and allocation authorities granted in the EPAA were scheduled to expire on August 30, 1975. During the summer and fall of 1975, when Congress faced a decision regarding extension of controls, attention had shifted from dealing with an acute shortage to dealing with the consequences of the high price of imported oil. Between August 1973 and June 1974 the price of imported crude oil rose by about 400 percent. Despite price controls on domestic crude oil, this precipitate increase in the average cost of crude oil caused substantial increases in the cost of petroleum products to consumers. Those price increases were in turn seen by many economists as partially responsible for plunging the economy into a deep recession during 1974 and 1975.

Congress and President Ford took different positions on the extension of price controls, with Congress generally favoring slower removal of controls than was proposed by the President. The Energy Policy and Conservation Act (EPCA) passed in December 1975, was a compromise between those two positions. It made two important changes in oil price regulation: it rolled back the prices of some domestic crude oil and it provided for gradual easing of price controls over thirty-nine months beginning in February 1976. In all other respects, EPCA left the prior regulatory program in effect. The price rollback mandated in EPCA was accompanied by a set of energy conservation programs designed to substitute for higher prices in controlling demand and some non-price measures to increase production.

The legislative history of the EPCA reveals that Congress intended continued price controls to prevent the macroeconomic disturbances and increased cost of living that would result from a precipitate increase in energy prices. Despite the provision for easing of price controls, the legislative history establishes no clear intent to achieve ultimate decontrol. Indeed the committee report that accompanied the House version of EPCA made a strong case for continued controls.⁷

The EPCA required the President to develop a system of crude oil price controls that would result in an average price of domestic crude, at its first sale, of \$7.66 per barrel. At the time EPCA was passed, that average price was \$8.63. Consequently the Federal Energy Administration faced the task of revising the structure of price controls to reduce the weighted average price.

The EPCA also allowed the average price of domestic crude oil to rise at an annual rate not to exceed the rate of inflation plus three percent.

In August 1976 Congress amended the EPCA to allow average crude oil prices to increase at a rate of ten percent per year and to revise the structure of price controls. The Conference report on these amendments stated that "the dramatic change in the inflation rate [to three percent in mid-1976] itself evidences the ability of the economy to absorb more substantial real dollar price increases."⁸ Because of this change, the EPCA amended the EPCA to allow greater increases in crude oil prices. The EPCA directed FEA to use some of the newly allowable price increases to give additional incentives to the use of exotic methods to increase production from existing fields ("tertiary recovery") and to remove some regional crude oil price differences, and to exempt stripper wells from price controls.⁹

The current system of price controls was created under authority of the EPCA, as amended. All domestic crude oil is classified into two tiers. The third tier, imported oil, is not subject to price controls. Stripper well lease oil was also exempted from controls by Congress in August 1976 and is now part of the third tier.

The definition of the two lower tiers hinges on the concept of a "base production control level" (BPCL) of oil production. In the initial stage of implementation of EPCA, the base production control level for any property was set "equal to that property's average monthly production and sale of old crude oil during calendar year 1975."¹⁰

"Old oil" is synonymous with oil subject to price controls under the system that existed until February 1976.

If the quantity of oil produced on a property does not exceed the base production control level, all oil from that property falls in the lower tier of price controls. If production from a property exceeds the base production control level, the difference between actual production and the base production control level goes into the upper tier, and the remainder (equal to the base production control level) goes into the lower tier.

The upper tier also includes all oil from properties that began production after December 1972. Stripper well lease oil, initially included in the upper tier, was exempted from controls in August 1976. However, when the average price of domestic oil -- which must conform to requirements of EPCA -- is computed, all stripper well oil is assigned an upper tier price rather than the price actually paid. This computation, specified in the amendments to the EPCA, made it possible to increase the price of stripper well oil without lowering the price of some other category of domestic oil.

During the first month of the new price regulations (February 1976), ceiling prices on lower tier oil were identical to those which existed under the previous control program. The price ceiling on upper tier oil was below the level at which uncontrolled oil sold prior to enactment of the EPCA. The new price ceiling was set equal to the highest posted price for a particular grade on a particular field on September 30, 1975 less \$1.32 per barrel. Average

domestic crude oil prices between 1975 and 1977 are listed in Table I.

The changes in the definition of the Base Production Control Level and in domestic oil price ceilings constituted the first stage of implementation of EPCA. The initial stage of implementation of EPCA set the base production control level for each property at or below the rate of production at which the per barrel cost of increasing output equalled the lower tier ceiling price, except for some properties producing released oil during 1975. The second stage, announced in April 1976, provided for gradual increases in ceiling prices and gradual reduction in the BPCL for all properties which continued to produce only lower tier oil.¹¹

The adjustment in the base production control level was intended to prevent the increasing disincentive to increased production observed under the previous set of price controls, which specified a fixed based production control level. By eliminating this disincentive the adjustment eliminated much of the efficiency loss associated with price controls on fields producing only old oil under EPAA.

The reduction in BPCL was applied initially only to properties that had produced no new oil since 1973.¹² Any property that produced new oil after 1973 would be granted a reduction in the BPCL only after its production remained below the initial fixed BPCL for six consecutive months.

TABLE I: Average Domestic Crude Oil Prices

		<u>Old</u>	<u>New</u>	<u>Domestic Average</u>		
1975	January	5.05	11.28			7.61
	February	5.03	11.39			7.47
	March	5.03	11.47			7.57
	April	5.03	11.64			7.55
	May	5.03	11.69			7.52
	June	5.03	11.73			7.49
	July	5.03	12.30			7.75
	August	5.03	12.38			7.73
	September	5.04	12.46			7.75
	October	5.03	12.73			7.83
	November	5.03	12.39			7.80
	December	5.03	12.95			7.93
1976	January	5.02	12.99			8.63
		<u>Lower Tier</u>	<u>Upper Tier</u>			
	February	5.05	11.47			7.87
	March	5.07	11.39			7.79
	April	5.07	11.52			7.86
	May	5.13	11.47			7.87
	June	5.15	11.39			7.79
	July	5.19	11.52			7.86
	August	5.18	11.55			7.89
				<u>Actual Stripper</u>	<u>Actual Domestic Average</u>	<u>Imputed Domestic Average</u>
	September	5.17	11.65	13.21	8.39	8.19
	October	5.15	11.62	13.35	8.46	8.23
	November	5.17	11.62	13.31	8.62	8.40
	December	5.17	11.64	13.30	8.62	8.40
1977	January	5.17	11.44	13.27	8.50	8.28
	February	5.18	11.38	13.32	8.57	8.32

SOURCE: FEA Monthly Energy Review

The base production control level is reduced by means of an automatic, semi-annual adjustment based on "the actual, annual average production decline rate between 1972 and 1975 on a property-by-property basis."¹³

The gradual increase in the price of lower tier oil announced in 1976 was based on authority which EPCA gave the FEA to increase the average of all domestic oil prices at an annual rate not to exceed the rate of inflation plus an additional "incentive factor" of 3 percent. The combined incentive and inflation factors could not exceed 10 percent. FEA decided to begin by dividing the allowable price increases equally between upper and lower tier oil. However, FEA determined that as lower tier oil was reclassified into the upper tier, through operation of the BPCL adjustment, it would eventually become impossible to continue to raise both price ceilings at a rate greater than the rate of inflation. That is, the entire 3 percent incentive factor would be used up in moving lower tier oil to the upper tier. (FEA estimated that lower tier oil would decline from its 60 percent share of domestic production in 1976 to 36 percent in 1979.)¹⁴

At the point at which applying allowable price increases equally would cause the upper tier price to rise less rapidly than the rate of inflation, FEA planned to continue to increase the price of upper tier oil at the rate of inflation and to allow the price of lower tier oil to decline in real (but not nominal) dollars.¹⁵

Whereas the adjustment in the BPCL was intended to compensate for the effects of naturally declining production rates, the ceiling price adjustment was intended to compensate for the effects of inflation on costs of production. Inflation could, by shifting the marginal cost curve up, have an effect similar and additional to the effect of reservoir decline. The two adjustments result in a situation in which any increment to production that could be obtained through investment in enhanced recovery would be sold at upper tier prices.

The schedule of price increases announced by FEA is presented in Table II. That initial schedule was based on FEA's estimates of the average price of domestic crude oil in January 1976. New data collection methods revealed after several months that FEA had underestimated the average domestic price. To bring its regulations into compliance with EPCA, FEA "froze" all oil prices, delaying the schedule of increases. The first such delay of two months, was announced on June 30, 1976. As additional price data became available, they revealed that average prices were remaining above the levels allowed under EPCA. During 1976 the price "freeze" was extended two more times, and it remained in effect on December 31, 1976.

Amendments to the EPCA and changes originated by FEA in the definitions of oil that could be sold at upper tier prices also took effect during 1976. Their effect was to make the rate of decline in the proportion of lower tier oil in total domestic production greater than forecast. Table III shows that actual prices exceeded prices

TABLE II

FEA's initial schedule of crude prices*

Month		Lower Tier May 15, 1973, posted price (\$3.90)	Upper Tier Sept. 30, 1975, posted price (\$12.60)
February 1976	1.	PLUS: 1.35 (\$5.25)	MINUS: 1.32 (\$11.28)
	2.	1.38	1.25
	3.	1.41	1.18
	4.	1.45	1.11
	5.	1.48	1.05
	6.	1.51	.97
	7.	1.54	.90
	8.	1.58	.83
	9.	1.61	.76
	10.	1.64	.69
	11.	1.68	.62
	12.	1.71	.55
February 1977	13.	1.74 (\$5.64)	.47 (\$12.13)
	14.	1.77	.41
	15.	1.80	.34
	16.	1.83	.28
	17.	1.87	.21
	18.	1.89	.15
	19.	1.93	.08
	20.	1.96	.01
	21.	1.99	PLUS: .05
	22.	2.02	.12
	23.	2.05	.19
	24.	2.08	.26
February 1978	25.	2.12 (\$6.02)	.33 (\$12.83)
	26.	2.14	.38
	27.	2.16	.43
	28.	2.19	.48
	29.	2.19	.55
	30.	2.19	.62
	31.	2.20	.70
	32.	2.21	.77
	33.	2.21	.84
	34.	2.22	.92
	35.	2.22	.99
	36.	2.23	1.07
February 1979	37.	2.23 (\$6.13)	1.14 (\$13.74)
	38.	2.25	1.22
	39.	2.26	1.29
	40.	2.26 (\$6.16)	1.35 (\$13.95)

(*Prices are based on the current rate of inflation, and will be revised at 6-month intervals to reflect changing inflation rates and congressional actions, including possibly an increase in the current 3% incentive rate.)

SOURCE: Oil and Gas Journal, April 1976, p. 26.

allowable under EPC throughout 1976. "Cumulative excess receipts" equal the amounts by which revenues from crude oil sales exceeded the level they would have reached if price ceilings allowable under EPCA had been in effect.

In January 1977 FEA acted to remove excess receipts by reducing upper tier price ceilings by \$.20, and in March it reduced price ceilings by a further \$.45. The schedule of price adjustments actually in effect between February 1976 and August 1977, resulting from these freezes and adjustments, is reproduced as Table IV.¹⁶

On September 9, 1977 FEA announced its final system of crude oil price ceilings. Because excess receipts had been eliminated, crude oil prices could again be allowed to rise. FEA announced that upper tier prices would be returned to their February 1976 level.¹⁷ Thereafter upper and lower tier prices would be increased at a rate equal to the rate of inflation. Reclassification of lower tier oil into the upper tier through operation of the automatic BPCL adjustment and incentives to expensive production techniques would continue. FEA estimated that reclassification plus scheduled ceiling price increases would just use up the statutory 10 percent annual rate of increase in the average price of domestic crude oil. Sufficient slack was, however, believed to exist that incentive prices for tertiary and newly discovered oil, proposed in the National Energy Plan, would be possible.¹⁸

Whether these price ceilings will continue indefinitely is up to the Congress. The EPCA made crude oil price controls mandatory

TABLE IV: Actual Price Adjustments During 1976 and 1977

	Lower Tier May 15, 1973 <u>posted price plus</u>	Upper Tier Sept. 30, 1975 <u>posted price less</u>
1976 February	1.35	1.32
March	1.38	1.25
April	1.41	1.18
May	1.45	1.11
June	1.48	1.05
July	1.48	1.05
August	1.48	1.05
September	1.48	1.05
October	1.48	1.05
November	1.48	1.05
December	1.48	1.05
1977 January	1.48	1.25
February	1.48	1.25
March	1.48	1.70
April	1.48	1.70
May	1.48	1.70
June	1.48	1.70
July	1.48	1.70
August	1.48	1.70
September	1.51	1.44
October	1.54	1.18
November	1.58	.92

SOURCE: 42 Federal Register 45289, Sept. 9, 1977

for 39 months. Thereafter, the President was granted discretionary authority to retain controls for two more years. On that date all price control authority would lapse.

If controls were allowed to lapse in 1979, all domestic oil prices would rise rapidly to about world price levels. Three factors would determine the impact of that increase on consumer purchasing power: the level of price ceilings on various tiers, the amount of oil in each tier, and the level of world oil prices. The amount of oil controlled at lower and upper tier prices depends on the response of production decisions to the incentives to increased production provided by the multi-tier system. Extrapolation of current trends suggests that in 1979 lower tier oil might be 30 percent of domestic production, upper tier 56 percent, and stripper well oil 14 percent of 6 billion barrels of production.

Fitting an exponential time trend to the average refiner acquisition cost of crude oil (net of import fees) between January 1975 and February 1977 provides an estimate of the rate at which world oil prices have increased since the initial round of drastic increases.¹⁹ The estimated rate of increase, 8.3 percent per year, is close enough to historical inflation rates to be consistent with OPEC's intention of raising prices at approximately the rate of inflation in key currencies. It also fits with some explorations of optimal pricing policies for the cartel, which predict no increase in constant dollar world prices (Cremer and Wietzman) or falling prices until 1980 and subsequent increases (Hnyilicza and Pindyck).

In the subsequent analysis both constant (real) prices and increases on the order of 2 percent above inflation are considered.

If the 8.3 percent annual rate actually continued, world oil prices in 1979 would be \$17.50 per barrel. Assuming that inflation in the U.S. were about 6 percent annually, and that price ceilings increased at that rate, upper tier prices would reach \$13.44 and lower tier \$6.02 in May 1979. Instant decontrol on that date would increase total expenditures on domestic crude oil by about \$20 billion. This increase is of the same order of magnitude (in constant dollars) as the increase that was estimated in 1975 if all price controls had been allowed to lapse on expiration of EPCA.²⁰ If energy policy goals and macroeconomic conditions were unchanged since that time, the consequences of such a sudden increase would be unacceptable.

Under current law, price controls may continue for an additional 24 months. To overtake the world oil price between 1979 and 1981, upper tier prices would have to increase at an annual rate of 14 percent and lower tier price at a rate of 33 percent per year, again assuming a 8.3 percent rate of increase in world prices. Table V presents similar calculations of rates of increase required to meet oil prices under other scenarios.

TABLE V

Annual Rates of Price Increase Required to Overtake World Prices

	Overtake by May 1979	Overtake by May 1981	Current Policy to 1979 Overtake by 1881	
			1977-79	1979-81
Lower Tier	55.0%	33.3%	6.0%	61.0%
Upper Tier	17.5%	14.1%	6.0%	20.0%
Average Prices (Assuming 2-1 upper to lower tier ration)	30.0%	20.0%		
Average Prices if only upper tier moves	9.8%	7.9%		

III. STATIC ANALYSIS OF CRUDE OIL PRICE CONTROLS

To characterize an efficient allocation of resources in oil production and consumption it is necessary to examine the market for crude oil. Demand for crude oil, by refiners, is a derived demand based on consumer demand for petroleum products. If there were no effective price controls on refiners, consumer prices (and demand) would vary with the cost of crude oil to refiners. With adequate competition in the refining industry, the price a refiner is willing to pay for crude oil is a measure of the amount consumers are willing to pay for petroleum products.

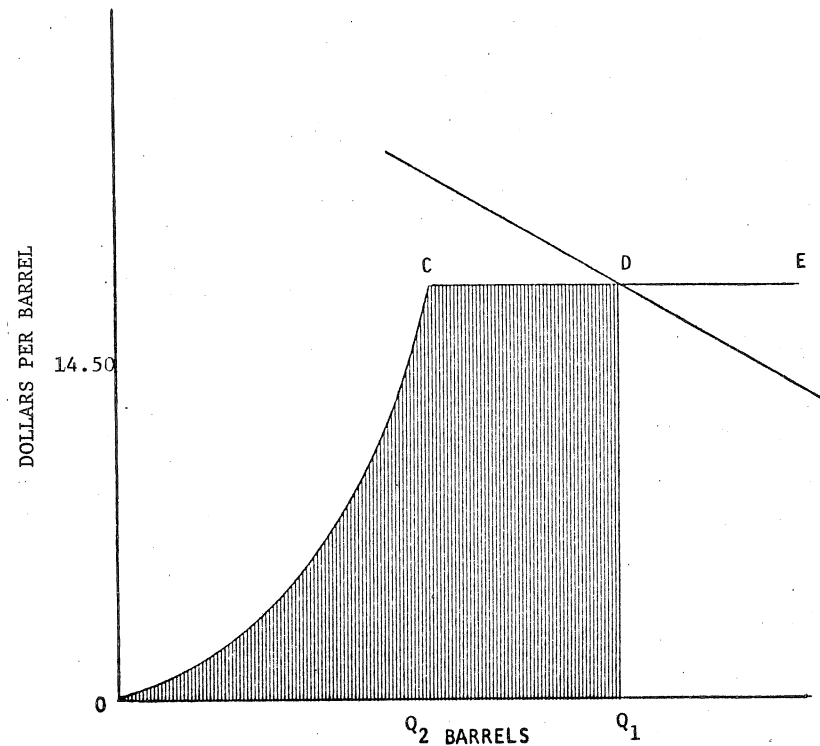
In the absence of crude oil price controls, domestic crude oil would sell at a price approximately equal to the landed cost of imported crude oil of similar characteristics.²¹ The interaction of domestic markets with world prices is depicted in Figure 1.

Supply of crude oil would, if there were no price controls on domestic crude oil, be represented by the curve OCDE. Up to \$14.50 per barrel (the 1977 world price) OC represents domestic supply; at \$14.50 per barrel unlimited supplies of imports are available. Since demand at \$14.50 per barrel (Q_1) exceeds domestic supply at that price (Q_2), the quantity $Q_1 - Q_2$ of oil would be imported.

Efficiency in Crude Oil Production

With a given level of energy demand, efficient production of crude oil implies keeping the total cost of oil -- the total

Figure 1
Supply and Demand for Crude Oil



resources used to produce oil domestically to pay for imported oil -- as low as possible. In order to achieve the most efficient allocation of resources in oil production, domestic oil production should include all oil that can be produced at a unit cost less than the price of imported oil. This efficient use of resources requires that production rates for all domestic oil fields be adjusted so that marginal cost -- the cost of increasing output by one unit -- is equal everywhere.²² Marginal cost of domestic production should also equal the price of imported oil. If marginal cost of domestic production is greater than the cost of imported oil, it would be possible to save resources by decreasing domestic output and increasing imports. Alternatively, if marginal cost of any domestic energy production is less than the cost of imports, it would be possible to save resources by increasing domestic production and reducing imports.

The effects of price controls on economic efficiency in crude oil production can be analyzed by finding how they alter the position the shape of the domestic supply curve OC. The area underneath the domestic import and supply curve shaded vertically in Figure 1 equals the total cost of crude oil. If the conditions of economic efficiency are satisfied, that area will be a minimum. Price regulations that increase the total cost of crude oil production impose an efficiency loss equal to the change in cost.

Economic Efficiency in Crude Oil Demand

An efficient level of demand for crude oil would be one in which oil is used only in ways that have an economic value no less, per unit of oil consumed, than the price of imported oil. This result could be achieved if each consumer paid a price for refined products that was based on the cost of imported oil. As long as demand exceeds domestic supply, every change in demand changes the level of imports in a like amount, increasing or decreasing the energy bill by the cost of imports. Unless consumers pay the full price of oil that they cause to be imported, consumption decisions will not be based on the real trade-offs involved in energy use. Consequently, a system which charges consumers less than the cost of imports can create a loss in efficiency.

Other Criteria

The legislative history of oil price controls makes it clear that an additional criterion for evaluating crude oil programs has to do with the distribution of wealth. Congress intended that price controls should prevent the transfer of income from oil consumers to oil producers and owners of oil properties. The magnitude of that transfer can be estimated by subtracting the revenues that crude oil producers actually receive from selling domestic crude oil under price controls from the amount they would have earned on that quantity of crude oil in the absence of price controls. The transfer of income is a cost to one sector of the economy, but a gain to another. The cost

and the gain cancel each other out when viewed from the point of view of economic efficiency.

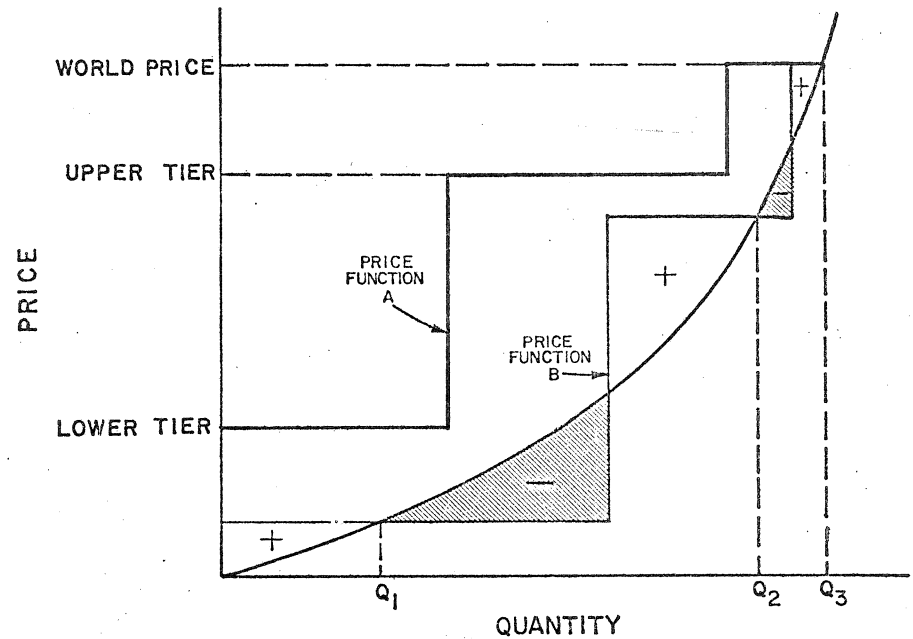
Another criterion by which oil price controls may be judged is their impact on oil imports. The efficiency criterion specifies a level of imports at which the cost of oil production is a minimum. Because of the potential damage which reduction in supplies or increases in the price of imported oil could cause, a case can be made that imports should be lower than the level at which the cost of increasing domestic production equals the price of imports.

Estimation of Welfare Losses in Production

Because oil price ceilings are set on a property by property basis, evaluation of those controls requires shifting perspective from a domestic supply curve to an individual property marginal cost curve (Figure 2). The area above the marginal cost curve and below a horizontal line at the selling price of crude oil equals producers' profits. A multi-part pricing system can, in principle, transfer some of those profits to consumers without changing crude oil production. The current, two tier system of prices for domestic crude oil can be superimposed on the marginal cost curve as a step function. So long as the price function is entirely above the marginal cost curve, it should have no effect on production decisions. If the price function offers market level prices at an output level less than that at which marginal

FIGURE 2

Price Ceilings and Oil Production



cost equals market price, there will be no marginal effect on output. But if the price function crosses the marginal cost curve, there may be a global effect on production decisions.

Price function A, for example, lies entirely above the marginal cost curve. The profit-maximizing choice is to produce at Q_3 , just as it would be if all output could be sold at the world price. But with profit function B that need not be the case. Profits are the difference between the triangle labelled (+) and those labelled (-). Even though marginal cost equals price at Q_3 , total profits may be negative when Q_3 is produced, or they may be positive but smaller than profits from producing Q_1 or Q_2 (where marginal cost also equals price).

The more tiers there are, the closer the price function can come to approximating the marginal cost curve. Putting the price function closer to the marginal cost curve makes it possible to reduce profits and the average price of domestic crude oil without affecting production incentives.

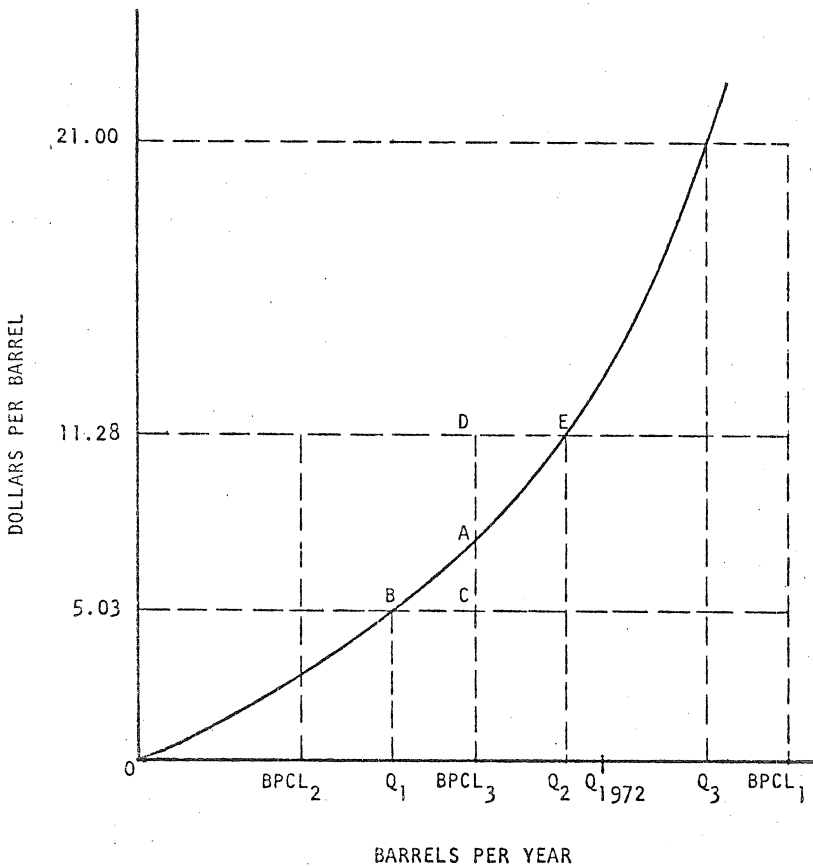
Current price controls and proposals in the National Energy Plan appear to follow the route of approximating the marginal cost curve for each property with a price function that lies uniformly above it. Currently all domestic crude oil subject to price controls is subject to a two tier system with an upper tier price below the world level. But proposals to allow high cost increments to production to be sold at market prices could add a third tier such as that depicted in Figure 2.

The new regulations promulgated in January 1976 also represented an attempt to make pure ceilings neutral. FEA changed the base production control level from its previous definition, actual production in each month of 1972 to a new definition, average monthly production of oil subject to price controls in 1975. Producers could choose between taking the new level or retaining the old. At the same time FEA eliminated all existing "cumulative deficiencies."²³

When the change was announced, the production level that would be profitable at lower tier prices was moving further and further below the old BPCL, thus diminishing the profits to be obtained from additional production. The effect of moving the BPCL to equal the amount of oil being produced when the program went into effect is illustrated in Figure 3. In 1975 each producer who produced only old oil was setting output at, say Q_1 , the point at which marginal cost equalled the price at which old oil could be sold (on average \$5.03). Such producers would have faced a high base production control level, such as $BPCL_1$, based on production in 1972. By moving the base production control level down to Q_1 , FEA insured that any producer who increased output above its 1975 level could sell the entire increment at upper tier prices.

The situation was more complex for producers with new and released oil in 1975. Released oil is excluded from the "old" oil production rate in computing the BPCL. With released oil, marginal revenue equalled the world price of oil plus the difference between world and controlled prices, about \$21, in December 1975. Some

Figure 3
Effects of BPCL on Production Levels



producers who had released oil under the old regulatory system would be assigned a BPCL (such as BPCL₂) lower than the amount of oil they would be willing to produce at \$5.00 per barrel. However, the extra revenue that results from this situation is not changed by output adjustments and does not affect marginal revenue; consequently the efficiency of production is undisturbed. Such producers would reduce output from Q₃ to Q₂, because without released oil the revenue derived from selling one additional barrel of oil was only equal to the upper tier price, on average \$11.28 in 1976.

Others could be given a base production control level higher than Q₁, the point at which additional output begins to cost more than the lower tier price, and below Q₂, the point at which additional output costs more than the upper tier price. In Figure 3, for example, a producer with a 1972 production level of Q₁₉₇₂ might have chosen in 1975 to produce at the level Q₃, in response to the incentive of released oil. Then new oil production in 1975 would be Q₃-Q₁₉₇₂. Since each barrel of new oil released one barrel of old oil from controls, an amount of oil equal to Q₃-Q₁₉₇₂ must be subtracted from the 1972 output level (Q₁₉₇₂) to determine how much old oil was being produced in 1975. Figure 14 is drawn so that the difference between BPCL₃ and Q₁₉₇₂ equals the difference between Q₃ and Q₁₉₇₂. Consequently BPCL₃, the amount of price controlled oil produced in 1975, is the base production control level assigned under current FEA regulations. That base production control level may be between Q₁ and Q₂.

Whereas under previous regulations, reducing output from Q_3 to Q_2 would have reduced revenues by \$21 per barrel, it would reduce revenues by only \$11.28 under the current system. Consequently it would be expected that all wells producing new and released oil would reduce output from Q_3 to Q_2 , the point at which further reduction would reduce cost by less than the \$11.28 per barrel revenue loss.

However, producers of released oil in 1975 find themselves in a situation in which losses caused by selling some oil at lower tier prices exceed the profits earned selling the remainder at upper tier prices. Without released oil, producers could find themselves losing money unless production were allowed to fall back to low levels. If the area of the triangle ADE were less than the area of the triangle ABC, such a producer would contract to Q_1 because any higher output level, such as Q_2 , would reduce profits. This result would be contrary to the intention of the regulations, which were designed to ensure that all domestic oil that could be brought out of the ground at a cost no greater than the upper tier price should be produced.

As long as the base production control level is kept at or below the hypothetical production rate at which marginal cost equals the lower tier price, static analysis predicts that the producer will choose the same production rate that would be chosen if all oil produced could be sold at upper tier price. That hypothetical production rate can be observed if the producer does not produce any upper tier oil: for then actual production will equal the production rate at which marginal cost equals

the ceiling. If a producer does sell some oil at upper tier prices, the appropriate place to put the BPCL can only be calculated hypothetically: actual production will be at the rate which sets marginal cost equal to the upper tier price.

The automatic BPCL adjustment applies only to properties that produce no new oil. Once new oil is produced, the BPCL is fixed. If the marginal cost curve shifts upward over time, some properties may reach a situation in which continued production at the rate at which marginal cost equals the upper tier price is unprofitable.

The exemption of stripper well oil from price controls may also provide an incentive to reduce production. However, it is probably unfair to attribute inefficiencies resulting from the stripper well exemption to current price controls. Favoritism toward stripper wells dates back to the days of market demand pro-rationing in Texas and Louisiana;²⁴ whatever political forces support it appear sufficiently strong to provide favorable treatment (and inefficient production methods) in any regulatory setting.

If the stripper well exemption is ignored and if the fixed BPCL for properties producing upper tier oil does not immediately create a disincentive to increased production, the static model implies that the lower tier price will be irrelevant to production decisions.

Having an upper tier ceiling price below the world price of oil would reduce the efficiency of crude oil production. By November 1977 the upper tier price is likely to be about \$3 per barrel less

than the average refiner acquisition cost of imported oil. Consequently some domestic production that would cost less, per barrel, than imported oil is likely to be foregone.

Effects on Production from Existing Properties

The upper tier price is not likely to be a significant hindrance to maximum production from existing properties. Some of that production could come from enhanced recovery projects, which involve relatively large, discrete investments that would provide an acceptable rate of return at oil prices of either \$11.28 or \$14.50 per barrel. During 1975 FEA estimated that at least half of the oil that would be produced using enhanced recovery if prices were decontrolled would also be produced with \$7.00 per barrel prices. The exemption of tertiary recovery projects from controls is likely to allow most enhanced recovery projects profitable at uncontrolled prices to proceed. FEA estimates that the exemption will increase oil production to 300,000 barrels in 1979.²⁵ This conclusion is quite sensitive to the exclusion of dynamic effects.

There is some evidence that FEA's revisions of lower tier price controls did provide an incentive to increasing production from existing properties. In October 1976 the Oil and Gas Journal reported that activity directed at renovating and increasing production from existing fields had reached the highest level reported since 1973.²⁶

Effects on Exploration and Development

Upper tier price controls are more likely to retard exploration and development of new oil properties than they are to deter investment in enhanced recovery. Until the change to the three tier price system, all production from a well drilled on a new property could be sold at uncontrolled prices. The new price regulations rolled that price back by over \$2.00 (\$1.35 plus the increase in the price of imports between September 1975 and January 1976).

It is clear that the price rollback cannot have encouraged additional exploration and development of new oil reserves, but it is difficult to quantify the resulting loss in a static model because of the variable relation between reserve additions and annual production rates.

The annual welfare loss that such a decline in production could cause can be bounded roughly by comparing projections of U.S. oil production in 1985 with and without price controls. With some crude interpolations, one can infer from FEA projections that maintaining a ceiling price of about \$11.50 (in constant dollars) until 1985 would reduce U.S. oil production by about 1.1 million barrels per day in 1985.

Since upper tier prices are about \$3 per barrel less than current price of imports and production prevented by that price must cost somewhere between upper tier and import prices, a reasonable estimate of the cost of the 1.1 million barrels per day production is \$12.50 per barrel, \$1.50 less than the price of imports. If that production could be obtained at a price \$1.50 less than the price of

imports, the annual welfare loss would be about \$600-million. In Figure 4, this welfare loss is represented as the shaded area labelled I.

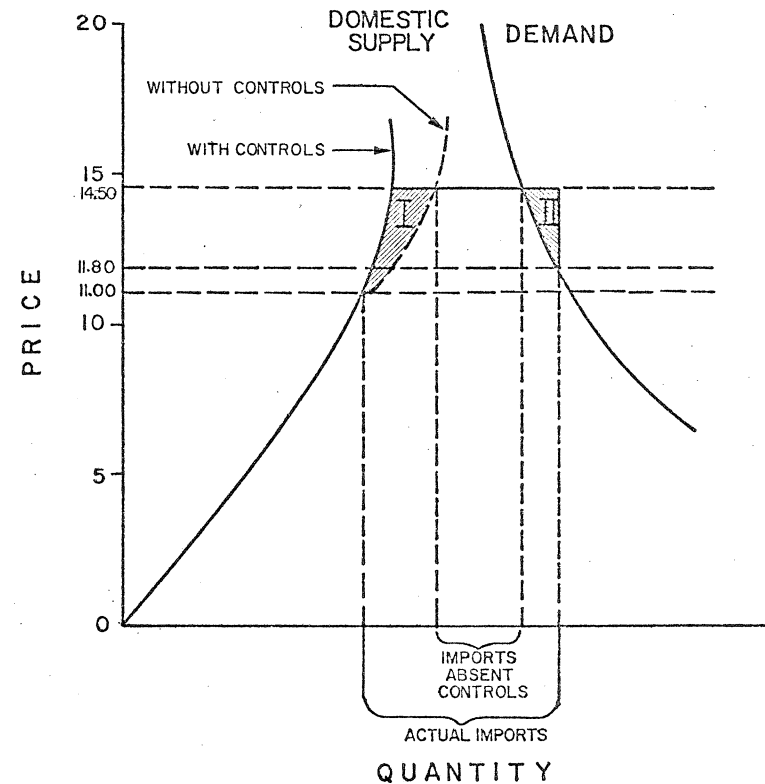
This number is considerably less than that arrived at by Hall and Pindyck. However, they estimate the difference between controlled and market prices by calculating the difference between the average domestic price and the price of imports. The upper tier price is, however, the only relevant one for predicting supply response under the current system of controls. Their guess at a supply elasticity of .2 implies that a price increase of 25 percent $(= (\text{world price} - \text{upper tier}) / \text{upper tier})$ would increase supply by 5 percent. Currently domestic crude oil production of 8 million barrels per day would have been 400,000 barrels per day in the absence of controls. Using the same cost estimates as above, this would imply an annual welfare loss of about \$200,000 million. The unitary price elasticity of reserves and production reported by Erickson, Millsaps, and Spann would imply a welfare cost on the order of \$1 billion.

Crude Oil Prices and Oil Demand

Because of the entitlements system, each refiner perceives the cost of additional crude oil imports as equal to the average cost of crude oil. That average cost is actually a weighted average of the prices of controlled, uncontrolled, and imported oil. In a free refined product market, competition would make refined product prices equal to the sum of marginal refining costs and the cost of

FIGURE 4

Welfare Losses of Price Controls



incremental crude oil supplies. With no price controls, incremental cost would equal the price of imports. With price controls and entitlements, it equals the lower average cost of crude oil.

Efficiency in the use of petroleum products requires that all consumers pay a price based on the cost of imported oil. With price controls and entitlements, however, consumers pay less than the full price of crude oil that they cause to be imported.²⁷ Consequently consumption decisions are not based on the real economic trade-offs involved in petroleum use. Since prices of petroleum products are below the cost of the oil that must be imported to satisfy demand, consumers will use petroleum products in applications in which the benefit to the consumer is less than the cost of imported oil. More oil will be consumed than would be if prices were established on unregulated markets. The magnitude of the resulting loss depends on how demand responds to price.

One measure of the efficiency loss due to the effect of price controls and entitlements on demand is illustrated in Figure 4. Efficiency loss is equal to the difference between what it costs to import a certain quantity of oil and the amount that consumers are actually willing to pay to have that amount of oil. This difference is equal to the triangle labelled II in Figure 4, which may be estimated by subtracting total willingness to pay for the quantity $Q_3 - Q_1$ (the area of ABCD) from the total cost of that quantity of imports. Q_1 is demand for oil in the absence of controls, while Q_3 is demand with price controls and entitlements. $Q_3 - Q_1$ equals the increase in imports that results from average cost pricing of crude oil.

Welfare losses due to consumer response to average cost pricing of oil are an intrinsic part of effective crude oil price controls. Entitlements provide a subsidy to imports by causing refined product prices to reflect average crude oil costs even though oil must be imported to satisfy demand at those prices. The subsidy is an inevitable result of the decision to use domestic crude oil price controls to hold down prices facing consumers. Because of the subsidy, price controls result in an inefficiently high level of demand for imports. Consumers are offered petroleum products as if the marginal cost of production included crude oil inputs at \$10 per barrel, whereas the true marginal cost curve is at least three dollars higher (for any demand levels that imply imports).

The difference between average refiner cost of imported oil and the composite of all crude oil including domestic oil and imports, was about \$2.70 during early 1977 (\$14.50-\$11.80).²⁸ Consequently, decontrol of all oil would raise the cost of crude oil passed on to consumers by about 25 percent in 1977.

To estimate that welfare loss, estimates of the price elasticity of demand for crude oil are required. Removal of controls in 1977 would increase average crude oil prices by about 25 percent. Crude oil consumption in 1976 was 4.9 billion barrels.²⁹ If a four percent increase in price reduced demand by 1 percent (a price elasticity of -0.25) removal of controls would reduce demand by 300 million barrels (.25 x .25 x 4.9 billion barrels). Thus the amount paid for imports -- since such a reduction in demand would create an equal reduction in imports -- would fall by \$4.3 billion (in February

1977 with import price = \$14.50 per barrel). To estimate the welfare improvement that results from the reduction in imports, it is necessary to subtract from \$4.3 billion the value consumers would place on their foregone consumption. That value must be at least \$11.80 per barrel (February 1977 average price), since that is what consumers were paying (through refiners) for crude oil, or \$3.5 billion. Thus welfare loss when the price elasticity is .25 is no larger than \$800 million, and probably less. It would be less because consumers would very likely be willing to pay more than \$11.80 (but less than \$14.50, the world market price) for some of the oil consumption which is foregone when prices rise. Taking this effect into account and assuming constant price elasticity suggest that the welfare loss from increased imports is on the order of \$400 million.

A price elasticity of .25 is a middle ground estimate. Some authorities have estimated elasticities as low as .1, and others as high as .5.³⁰ That range of elasticity estimates implies that welfare loss could be between one hundred fifty million and eight hundred million dollars annually. Based on 1980 demand projections at various prices reported in FEA's 1976 National Energy Outlook, the loss would be under \$1 billion per year.³¹

Under current conditions crude oil price controls also transfer to oil consumers over \$15 billion per year of revenue that would go to domestic oil producers and owners of oil fields if all oil sold at world prices. In May 1976, refineries processed 140 million barrels of crude purchased at an average lower tier price

of \$5.50, and 110 million barrels of upper tier crude oil purchased at an average price of \$12.50. If, instead, refineries had purchased these 250 million barrels at the average refiner's acquisition cost of imports, \$13.50, they would have spent an additional \$1,285 million in May.³² Assuming that all these costs were passed through to consumers, and converting them to annual figures, the petroleum products would have cost about \$15 billion more in 1976. Price controls on upper tier oil alone were responsible, according to these figures, for an annual income transfer of \$1,985 million.

IV. DYNAMIC ANALYSIS OF PRODUCTION UNDER PRICE CONTROLS

Essential features of crude oil production cannot readily be represented in a static model. This gap was hinted at earlier with the mention of the tendency of marginal cost curves to rise over time as a reserve is depleted. Because an irreversible investment may be required to increase the rate of production from a reservoir, the entire path of future prices may also be relevant to current decisions.

A dynamic model that includes even the central features of petroleum production is quite unwieldy. A model which simultaneously included depletion (the fact that reserves are finite and that what is produced now reduces future production possibilities), rate sensitivity (the dependence of ultimate recovery on instantaneous production rates) and dependence of extraction cost on remaining reserves would be more sophisticated than any yet explored in the theoretical literature.³³ However, it is possible to begin a preliminary exploration of the dynamics of price control with the simplest model, in which it is assumed that marginal extraction costs are not affected by past production but that there is only a finite stock to be recovered.

This section is divided into four parts: discussion of an efficiency criterion, implications of continued controls, paths to decontrol, and analysis of multi-part pricing in a dynamic context.

A Dynamic Efficiency Criterion

As an introduction to the dynamic model and for future reference, I will begin by characterizing conditions for efficient

resource allocation in domestic crude oil production over time. In a static framework, welfare losses on the crude oil production side can be measured in terms of the savings in resource cost that could be achieved by substituting domestic production for imports. In a dynamic framework the timing of domestic production and the amount of oil ultimately recovered become the central questions.

The problem can be formulated as one of maximizing the discounted present value of the difference between the value of crude oil to ultimate consumers and the cost of obtaining crude oil. Let X_t^1 be the amount of crude oil produced domestically, X_t^2 the amount imported, p_t^w the world price of oil, $C(X_t^1)$ the cost of producing domestic crude oil, $U(X_t^1 + X_t^2)$ total willingness to pay for crude oil, and $R(t)$ the stock of recoverable domestic crude oil available, with t a time index. Then the objective can be formulated as maximizing

$$\int_0^T [U(X_t^1 + X_t^2) - C(X_t^1) - p_t^w X_t^2] e^{-rt} dt$$

subject to the constraints

$$R(t) \geq 0 \quad x_t \geq 0$$

and the equation of motion

$$\dot{R}(t) = -X_t^1$$

which states that the rate of change in recoverable resources over time equals the rate of extraction.

This problem is solved by writing the Hamiltonian

$$H = [U(x_t^1 + x_t^2) - C(x_t^1) - p_t^w x_t^2 - \lambda_t x_t^1] e^{-rt}$$

where λ_t is a shadow price on the remaining stock of resources.

(Time subscripts will be dropped where their presence is obvious.)

Necessary conditions for an interior maximum are

$$\frac{\partial H}{\partial x_1} = U' - C' - \lambda = 0$$

$$\frac{\partial H}{\partial x_2} = U' - p_w = 0$$

$$\dot{\lambda} = \lambda r.$$

At the time of domestic resource exhaustion T two transversality conditions must be satisfied:

$$U(x_T^1 + x_T^2) - C(x_T^1) - p_T^w x_T^2 = \lambda_T x_T^1$$

$$\lambda_T = U'(x_T^1 + x_T^2) - C'(x_T^1).$$

Because the world price is fixed exogenously, these necessary conditions imply the following conditions on domestic production when all crude oil sells at the world price:

$$p_w - C' - \lambda = 0$$

$$\dot{\lambda} = \lambda r$$

and the transversality conditions

$$\lambda_T = U' - C'$$

$$p_T^w x_T^1 - C(x_T^1) - \lambda_T = 0.$$

These conditions determine domestic production, which will hereafter be labelled simply x_t , as a function of time. A function x_t satisfying the conditions will be referred to as an efficient production path.

It is easy to see that a domestic oil producer selling output at world market prices will choose the efficient production path in order to maximize the discounted present value of profits. It will

$$\text{maximize } \int_0^T e^{-rt} \{p_t^w x(t) - C(x(t))\} dt$$

subject to $\dot{R}(t) = -x(t)$, $R(t) \geq 0$, $x(t) \geq 0$. First order conditions for an interior solution are found by writing the Hamiltonian

$$H = e^{-rt} [p_t^w x_t - C(x_t) - \lambda_t x_t].$$

Necessary conditions require that

$$(1) \quad \frac{\partial H}{\partial x} = e^{-rt} [p_t^w - C'(x) - \lambda] = 0$$

and

$$(2) \quad \dot{\lambda} = (-\frac{\partial H}{\partial R}) = \lambda r.$$

Note that condition (1) requires that marginal cost be set equal to a value less than price. That is, λ corresponds to the user cost or royalty term identified in other studies of extraction of nonrenewable

resources. Consequently $x(t)$, the amount of oil extracted at time t , will always be less than that predicted in the static analysis that ignores depletion of the reservoir.

The time paths of extraction can be described qualitatively by differentiating (1) with respect to time to obtain

$$(3) \quad \dot{x}(t) = \frac{\dot{p}_w(t) - (p_w(t) - C'(x(t)))r}{C''(x(t))}.$$

If p_w is constant over time, so that $\dot{p}_w = 0$, $x(t) < 0$ and production rates always decrease over time. Typical production paths are graphed in Figure 5.

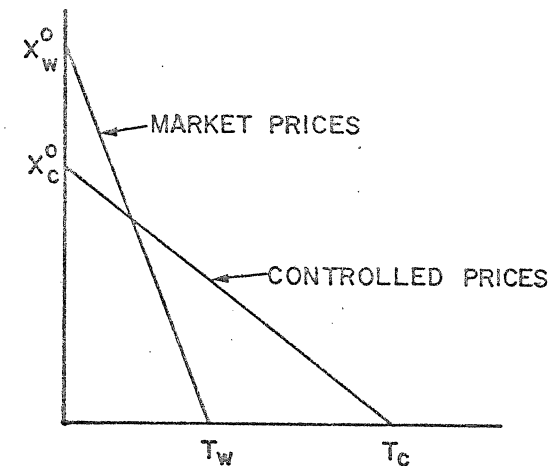
If there are lags in the adjustment of demand to price, the welfare effects of changing prices cannot be determined by looking at production paths alone. Different rates of price increase may imply different demand levels even at a time at which current prices are equal. But exploration of the dynamic response of energy demand to price increases is beyond the scope of this paper.³⁵ If the demand for crude oil depends only on current prices, welfare losses on the demand side can be estimated using a static analysis, as in the previous section.

Implications of Continued Controls

If domestic prices are controlled at a constant price $p_c < p_w$, a different production path will result. Let x_t^c be the production rate at time t under price controls. Then profit maximizing production rates can be derived from the Hamiltonian

FIGURE 5

Production Paths When Market and Ceiling Prices Are Constant



$$H = e^{-rt} [p_c x_c - C(x_c) - \lambda x_c].$$

Necessary conditions are

$$(4) \quad p_c - C'(x_c) - \lambda = 0$$

$$(5) \quad \dot{\lambda} = \lambda r.$$

Differentiating (4) with respect to time gives

$$(6) \quad \dot{x}_c = \frac{-r(p_c - C'(x_c))}{C''(x_c)}$$

if the price ceiling is constant over time.

The area under the production curve must always equal the total resource stock $R(0)$ (see Figure 5). If $p_c < p_w$ is also constant, (3) and (6) imply that at any production rate $\dot{x}(t)$ will be algebraically smaller (more negative) with market prices p_w than with controlled prices. Because the same total resource is available, the production curve under controlled prices must intersect the production curve with market prices from below. Initial production will be smaller and the date of depletion will be later with controls.

If prices vary over time, the characterization of time paths of production is more complex. Under current policy, price ceilings on upper and lower tier oil will remain constant in real terms. Past OPEC practice has been to raise prices at a somewhat higher rate. To explore the consequences of rising world oil prices, let $\alpha = p_w - p_c$.

A producer facing market prices can be represented as receiving the controlled price plus an increasing subsidy α , with the

Hamiltonian

$$H = e^{-rt} [p_c x_w + \alpha x_w - C(x_w) - \lambda x_w].$$

Necessary conditions are

$$(7) \quad p_c + \alpha - C' - \lambda = 0$$

$$(8) \quad \dot{\lambda} = \lambda r.$$

Differentiating (7) with respect to time and using (8) gives

$$(9) \quad \dot{x}_w = \frac{\dot{\alpha} - r(p_c - C'(x_w) + \alpha)}{C''(x_w)}.$$

If $\frac{\dot{\alpha}}{\alpha} = r$, that is if the difference between world and U.S. prices increases at the rate of interest, (6) becomes identical to (4). Since the same total extraction must be achieved, it follows that production rates will be identical to those under price controls.

If world prices rise at a rate that makes the proportionate rate of change in $p_w - p_c$ greater than r , Burness has proved that resources will be depleted sooner under price controls, and initial production rates will be higher than with market prices. If world prices rise at a rate such that $p_w - p_c$ increases at a proportionate rate less than r , resources will be extracted later and initial extraction rates will be lower.

If p_w increases at a constant proportionate rate δ , the proportionate rate of growth in $p_w - p_c$ will decrease over time and approach the limit δ .³⁴ If $\delta > r$, the proportionate rate of growth in $p_w - p_c$ will also remain above r . If $\delta < r$ but initially the

proportionate rate of growth in $p_w - p_c$ is above r , there will be a switch which makes it impossible to characterize the time path of production. If initially the rate of growth in $p_w - p_c$ is less than r (and $\delta < r$), it will always be less than r .

In real dollars, the world price in real terms would increase by at most 3 percent per year initially, if recent OPEC behavior continued. During 1976 average refiner acquisition cost of imports rose by \$.90, while the gap between upper tier and domestic and imported oil reached almost \$3. The rate of increase in the gap was about 33 percent. Consequently, it appears that U.S. oil production is in the ambiguous situation of a gap increasing initially at a rate above the rate of interest but then declining to a rate below the rate of interest. We can collect all these possibilities in three diagrams (Figure 6).

Suppose that for $0 < t < T_1$, $\frac{\dot{p}_w(t)}{p_w(t) - p_c(t)} > r$. Then

any intersection between 0 and T_1 has $\dot{x}_w > \dot{x}_c$, as in Figure 6a.

For $t > T_1$, $\frac{\dot{p}_w(t)}{p_w(t) - p_c(t)} < r$. Then $\dot{x}_w < \dot{x}_c$.

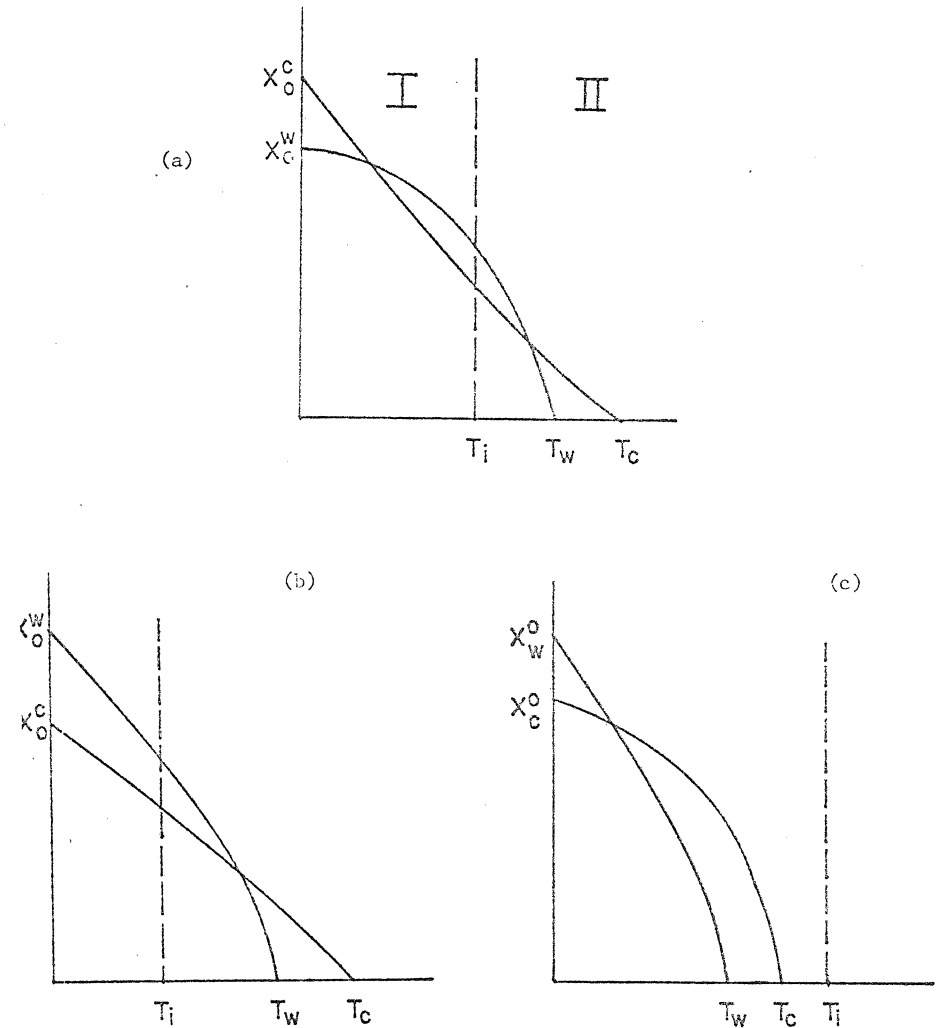
Consequently production curves can intersect once in Region I and once in Region II as drawn. Depletion under market prices cannot occur before T_1 , because then x_w would either lie completely below x_c (and depletion would not take place), the transversality conditions would be violated, or x_w would intersect x_c from above.

If $T_1 > T_c$ (depletion date under controls), $T_w > T_c$ and $x_w^0 < x_c^0$, as in Figure 6c. If $T_1 = 0$, $T_w < T_c$ and $x_w^0 > x_c^0$, as in

Figure 6b.

FIGURE 6

Production Paths with Rising Market Prices



The transversality conditions require that the terminal production rates $x_{T_w}^M$ and $x_{T_c}^c$, equal zero. Therefore, there are three possible configurations when $T_1 > 0$, as drawn in Figure 6: intersections in both regions, an intersection in region I only, or an intersection in region II only. If there is no intersection in region II, there must be an intersection in region I.

Region II, it will be remembered, consists of all time after T_1 , the date on which the proportionate rate of change in the gap between world and upper tier prices equals the rate of interest. If T_c , the date of depletion of a reservoir under price controls, is later than T_1 , there can be no intersection in Region II. During the sixties domestic crude oil prices did not rise in real terms (Cox and Wright, 1976) and were considerably lower than the current upper tier price. Consequently the depletion date of a typical reservoir in the sixties would be delayed relative to the date of a similar reservoir exploited under current upper tier prices. During the sixties a reservoir that lasted 20 - 30 years was unusually long-lived: consequently 20 years is probably a reasonable estimate of the life of most reservoirs under current upper tier price ceilings. With a 3 percent escalation (above inflation) in world prices, the rate of increase in the gap would be 5.4 percent annually after 20 years. With 2 percent escalation, the rate of increase would be 4.4 percent, and with 1 percent escalation, 3 percent after 20 years. These should be compared to a real interest rate (nominal rate less inflation rate). These calculations suggest that the date

at which most reservoirs are likely to be depleted under current price controls is prior to the date on which the rate of change in the gap equals the real rate of interest. Consequently the relation between production under price controls is likely to be that drawn in Figure 6c: initially, oil production under price controls would exceed production in the absence of controls, but production for sale at world prices would delay depletion.

These magnitudes make it appear that if domestic oil producers had not been subject to price controls and if they extrapolated recent OPEC pricing behavior, current U.S. oil production would be lower than it now is under price controls. The rising world price would give an incentive to delay production large enough to outweigh the incentive to increased production that would result from a higher current price.

Decontrol

If domestic upper tier prices were allowed to rise to meet world prices, domestic production would remain below the optimal production path for some time, and later rise above it. Production would also be lower than in the case of continued controls.

To see this consider the time paths

$$\dot{x}_c = \frac{\dot{p}_c - r(p_c - C'(x_c))}{C''(x_c)}$$

$$\dot{x}_w = \frac{\dot{p}_w - r(p_w - C'(x_w))}{C''(x_w)}$$

Then

$$\begin{aligned}\dot{x}_w - \dot{x}_c &= -rp_w + rp_c - \dot{p}_c + \dot{p}_w \\ &= r(p_c - p_w) - (\dot{p}_c - \dot{p}_w).\end{aligned}$$

If $x_w(t) = x_c(t)$ for some t , $p_w > p_c$, $\dot{p}_c > \dot{p}_w$, then $\dot{x}_w - \dot{x}_c < 0$.

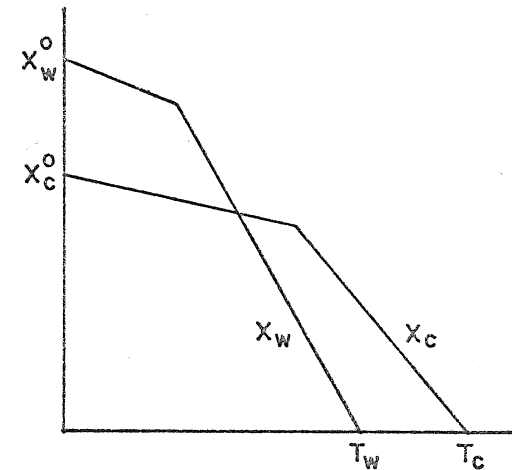
Consequently production paths will be related as in Figure 7, although it cannot be guaranteed that production rates will for all time.

The Implications of Multiple Tier Pricing

The static analysis discussed earlier led to the conclusion that if the price function lies uniformly above the marginal cost curve, price controls do not affect production. This conclusion no longer holds in the dynamic case.

FIGURE 7

Production Paths When Ceiling Prices Rise to World Prices



Let β be the base production control level applied to a particular reservoir. If upper tier oil is produced, β will be constant over time. If p_u = upper tier price, p_L = lower tier price, net revenue at any time t when $x_t > \beta_t$ will be

$$p_u(x_t - \beta_t) + p_L\beta_t - C(x_t).$$

The discounted present value of profits will be

$$\int_0^T e^{-rt} [p_u(x_t - \beta_t) + p_L\beta_t - C(x_t)] dt.$$

To maximize this expression, we form the Hamiltonian

$$e^{-rt} [p_u x_t - (p_u - p_L)\beta_t - C(x_t) - \lambda x_t]$$

and deduce the necessary conditions

$$p_u - C'(x) - \lambda = 0$$

$$\dot{\lambda} = \lambda r$$

$$\frac{p_u(x_t - \beta_t) + p_L\beta_t - C(x_t)}{x_t} = p_u - C'(x_t)$$

$$\lambda_T = p_u - C'(x_T).$$

This case now has exactly the form of one examined by Burness: he proves that the existence of what is essentially a lump sum tax, $(p_u - p_L)\beta_t$, which is collected for all time prior to depletion, will accelerate the date of depletion and cause extraction rates to be larger in every period.

Intuitively the reasons for this behavior are clear. In every time period that upper tier oil is produced, a fixed amount must be sold at the lower tier price. To maximize profits it is desirable to increase the rate of extraction, thus increasing the ratio of upper tier to lower tier oil produced over the life of the field. Again the structure of price controls has the effect of increasing extraction rates.

However, it is also possible under current regulations to produce no upper tier oil and to allow the BPCL to decline at the same rate observed between 1972 and 1975. If that decline rate is fast enough, it may be profitable to delay increasing production. Let γ be the decline rate. Then

$$\beta_t = \beta_0 e^{-\gamma t}.$$

Suppose a producer considers maintaining production at β_0 for one year, and then shifting to the profit maximizing production path with $x_t > \beta_t$. Delaying one year increases every future year's revenues by $(p_u - p_L)\beta_0\gamma$, but reduces the first year's revenue to $p_L\beta_0 - C(\beta_0)$.

To determine which is the better strategy, the producer will compare the present value of profits under two strategies. If production of upper tier oil begins immediately present value of profits is

$$PV_0 = \int_0^{\tilde{T}} e^{-rt} (p_u \tilde{x}_t - C(\tilde{x}_t) - (p_u - p_L)\beta_0) dt.$$

If production of upper tier oil is delayed one year, it is

$$PV_1 = p_L \beta_0 - C(\beta_0) + \int_1^{\hat{T}} e^{-rt} (p_u \hat{x}_t - C(\hat{x}_t) - (p_u - p_L) \beta_0 (1 - \gamma)) dt$$

because the BPCL declines to $\beta_0(1 - \gamma)$. The variables \tilde{x}_t and \hat{x}_t are production rates which maximize PV_0 and PV_1 , respectively, subject to $x_t > \beta_t$, $R(t) \geq 0$, and $\dot{R} = -x_t$. Consider

$$\begin{aligned} PV_0 - PV_1 &= \int_0^{\tilde{T}} e^{-rt} (p_u \tilde{x}_t - C(\tilde{x}_t)) dt - (p_L \beta_0 - C(\beta_0)) \\ &\quad - \int_1^{\hat{T}} e^{-rt} (p_u \hat{x}_t - C(\hat{x}_t)) dt \\ &\quad + (p_u - p_L) \beta_0 (1 - \gamma) \int_1^T e^{-rt} dt \\ &\quad - (p_u - p_L) \beta_0 \int_0^T e^{-rt} dt. \end{aligned}$$

If T and \hat{T} are large, $PV_0 - PV_1$ is approximately equal to

$$\begin{aligned} &\int_0^{\infty} e^{-rt} (p_u \tilde{x}_t - C(\tilde{x}_t)) dt \\ &\quad - (1 - r) \int_0^{\infty} e^{-rt} (p_u \hat{x}_{t+1} - C(\hat{x}_{t+1})) dt \\ &\quad + \frac{1}{r} \left[(p_u - p_L) \beta_0 (1 - \gamma) (1 - r) - (p_u - p_L) \beta_0 \right] \\ &\quad - (p_L \beta_0 - C(\beta_0)). \end{aligned}$$

The last two terms are negative, and tend to make the present value of profits larger if upper tier production is delayed. If \tilde{x}_t and \hat{x}_t are approximately equal for all t , the difference between the first and second terms will be positive. Consequently it is impossible to show that in general $PV_0 > PV_1$ or $PV_1 > PV_0$. But the larger is γ , the more likely it is that $PV_1 > PV_0$ and that delay will be the most profitable strategy.

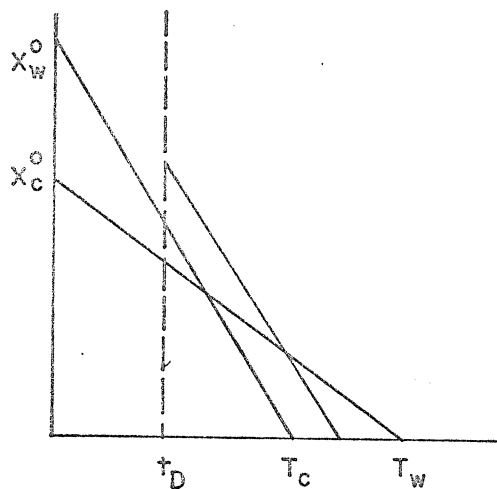
No quantitative conclusion about the significance of this incentive can be reached without data on extraction costs. But qualitatively the conclusion emerges that a declining base production control level can have the same effect on production as a rising lower tier price in real terms. The "user cost" which results can give an incentive to maintain production at the BPCL rather than respond to the incentive of an upper tier price. If the lower tier price is allowed to rise on a path to decontrol, a similar incentive to hold production below the BPCL could exist (as pointed out by Phelps and Smith).

Discontinuous Decontrol

The sudden lapse of oil price controls would, if unanticipated, produce a jump from one production path to another. Until the date of decontrol, production would follow the path beginning at x_c^0 in Figure 8. On that date a certain quantity of reserves would remain. To investigate subsequent production we can imagine that a new

FIGURE 8

Unanticipated Instantaneous Decontrol



vertical axis is drawn at t_D , the date of decontrol. If prices jump to a world price that is constant over time, production will increase discontinuously (to a path parallel to x_M), and decline more rapidly than under continued controls so that reserves are exhausted earlier. The sooner decontrol occurs, the more closely the resulting production path will approximate the optimum.

If decontrol is announced in advance, an entirely different outcome could be expected. A jump in price implies a jump in x_t as well. Moreover, as the date of decontrol approaches, the rate of return on delaying production will become larger and larger, so that x_t must drop below the curve x_c (and may become zero for some time). All of these results are common wisdom.

IV. CONCLUSION

The results of the dynamic analysis should be viewed with some caution. The simplest of dynamic models is used, and its assumptions are clearly at variance with the facts of petroleum production. The existence of fixed costs in petroleum extraction, associated with the indivisible and irreversible investment required to initiate enhanced recovery, and the difficulty of integrating exploratory and production activity in a single model make reliance on a model that assumes complete extraction of a fixed recoverable resource unwise. Ultimate recovery from a reservoir is clearly sensitive to price.

It is not possible to derive quantitative measures of welfare loss in a dynamic model without a numerical solution for the

optimal production path which may also depend on the dynamics of demand adjustment. Consequently in a dynamic framework the performance of price controls in terms of efficiency and distribution remains unknown. Nor are recommendations that one or another path to decontrol be taken appropriate without considerations of the macroeconomic implications of those paths.

But the comparison of dynamic and static models does reveal obvious discrepancies. In static analysis price controls increase output rates for all time and multiple tier price systems are neutral in their effect on production. In at least one dynamic model, neither of these conclusions holds. Further exploration of price controls in a dynamic context thus appears to be a matter of high priority in the agenda of research on regulation.

FOOTNOTES

1. For example, in Roush, p. 22, Cox and Wright (1977), p. 16, Phelps and Smith, pp. 50-53, and Montgomery, p. 70.
2. Some examples of this literature are Heal, Solow and Wan, and Dasgupta and Heal, and Stiglitz.
3. EPAA Sec 4(a).
4. House Report 93-628, "Emergency Petroleum Allocation Act," p. 25.
5. Ibid., p. 26
6. EPAA Sec 4(b)(1)(H) and (I).
7. House Report 94-340 "Energy Conservation and Oil Policy Act of 1975", pp. 5-8.
8. Senate Report 94-1119, "Energy Conservation and Production Act," p. 57.
9. Ibid., p. 11.

10. 41 Federal Register 4932, February 3, 1976.
11. 41 Federal Register 15566, April 13, 1976.
12. 41 Federal Register 15569, April 13, 1976.
13. 41 Federal Register 15566, April 13, 1976.
14. Oil and Gas Journal, March 8, 1976, p. 27.
15. 41 Federal Register 15569, April 13, 1976.
16. 42 Federal Register 45285, September 9, 1977.
17. Because of intervening inflation, this decision amounted to a decision to keep real (constant dollar) prices below the February 1976 level.
18. 42 Federal Register 45286, September 9, 1977.
19. The fitted equation is $\ln(\text{PRICE}) = 2.5 + .007(\text{MONTH})$; $R^2 = .88$.
20. Recovery: How Fast and How Far?, Congressional Budget Office, September 17, 1975.

21. Crude oil is not a homogenous commodity: viscosity, sulfur content and other characteristics vary and affect its value, Transportation costs also vary with the distance between wells and refineries, and can result in differing wellhead prices for identical crudes. Consequently, exact equality between average domestic prices and the landed cost of imports would be unlikely even without controls. Nevertheless the prices of imported oil would determine domestic prices in the manner described in the text.
22. Subject to the usual caveat regarding transport and quality differentials.
23. The cumulative deficiency is the amount by which total production has fallen below the total production that would have been achieved if in each month the production rate had equalled the BPCL. It must be made up out of production in excess of the BPCL before oil may be sold at upper tier prices.
24. See, for example, Adelman.
25. Oil and Gas Journal, November 1, 1976, p. 40.
26. Oil and Gas Journal, October 20, 1976.

27. This conclusion has been questioned recently by Phelps and Smith and by a Presidential Task Force. Both note that the entitlements system subsidizes domestic refining of foreign crude oil and thus creates an incentive to import crude oil rather than refined products. This could result in increasing domestic refining costs, which could reduce the cost saving promised consumers by crude oil price controls. For three reasons I find this argument unconvincing: (1) the difference between refined product prices and incremental crude oil costs has declined since prior to the introduction of entitlements, whereas the Phelps and Smith theory predicts that it should increase; (2) domestic refinery utilization is now at about the same percentage of capacity as it was in the sixties; since little new capacity has been created, there seems to have been little shift to domestic refining; (3) transportation costs weigh against use of refined products in many inland areas. Consequently, I maintain the assumption that all crude oil price reductions caused by price controls are passed through to consumers.

28. FEA Monthly Energy Review, May 1977.

29. Ibid.

30. As cited in Davidson, Falk, and Lee and in Hall and Pindyck.

31. Based on interpolations between 1980 demand projections at various prices reported in FEA's National Energy Outlook - 1976.

32. Based on refinery volume and cost data supplied by FEA Entitlements Program.

33. All of these aspects and more are explored for example, Kuller and Cummings. But their paper stops with discussion of the marginal conditions for optimality. Solving these conditions for a time path of production or determining the qualitative characteristics of that solution still appears behind the state of the art. Models of depletion alone have been explored extensively, for example, by Dasgupta and Heal and by Stiglitz. Matthews has characterized the effects of rate sensitivity, and dependence of extraction costs on recovery has recently been studied by Heal and by Solow and Wan.

34. This arithmetic relation is proved by examining the definition

$$\frac{\frac{d}{dt}(p_w - p_c)}{p_w - p_c} = \frac{\dot{p}_w}{p_w - p_c}.$$

If $\frac{\dot{p}_w}{p_w} = \delta$, a constant, then

$$\lim_{t \rightarrow \infty} \frac{\dot{p}_w}{p_w - p_c} = \delta.$$

Note that since δ is constant,

$$\frac{d}{dt}\left(\frac{\dot{p}_w}{p_w}\right) = \frac{p_w \ddot{p}_w - \dot{p}_w^2}{p_w^2} = 0, \quad p_w \ddot{p}_w - \dot{p}_w^2 = 0$$

and $\ddot{p}_w > 0$.

Therefore

$$\frac{d}{dt} \left(\frac{\dot{p}_w}{p_w - p_c} \right) = \frac{p_w \ddot{p}_w - \dot{p}_w^2 - p_c \ddot{p}_w}{(p_w - p_c)^2} = \frac{p_c \ddot{p}_w}{(p_w - p_c)^2} < 0.$$

And obviously $p_c > 0$ implies $\frac{\dot{p}_w}{p_w - p_c} > \frac{\dot{p}_w}{p_w}$. Therefore the rate of

change in the gap between market and controlled prices is greater than the rate of change in market prices, and it decreases continuously to approach the rate of change in market prices in the limit.

35. For a relevant analysis of the importance of lags in demand response in a dynamic model see Hnyilicza and Pindyck.

REFERENCES

Adelman, Morris, The World Petroleum Market (Baltimore:1972).

Burness, H. Stuart, "On the Taxation of Nonreplenishable Natural Resource," Journal of Environmental Economics and Management 3, (1976):289-311.

Cox, James C. and Arthur W. Wright, "The Effects on Refined Product Prices and Energy Independence of Decontrolling Crude Oil Prices," February 1977 (xerox).

_____, "The Determinants of Investment In Petroleum Reserves and Their Implications for Public Policy," American Economic Review 66, (1976):153-167.

Cremer, Jacques and Martin L. Weitzman, "OPEC and the Monopoly Price of World Oil," European Economic Review

Dasgupta, P. and G.M. Heal, "The Optimal Depletion of Natural Resources," Review of Economic Studies Symposium, (1974):3-28.

Davidson, P., "Policy Problems of the Crude Oil Industry," American Economic Review 53, (1963).

_____, L. Falk and H. Lee, "Oil: Its Time Allocation and Project Independence," in Brookings Papers in Economic Activity 2, (1974):411-448.

- Erickson, Edward W., Stephen W. Millsaps, and Robert M. Spann, "Oil Supply and Tax Incentives," Brookings Papers on Economic Activity 2, (1974):449-493.
- Hall, Robert E. and Robert S. Pindyck, "The Conflicting Goals of Energy Policy," Public Interest 47, (1977):3-15.
- Heal, G.M., "The Relationship Between Price and Extraction Cost for a Resource with a Backstop Technology," Bell Journal of Economics 7, (1976):71-378.
- Hnyiliczka, Esteban and Robert S. Pindyck, "Pricing Policies for a Two-Part Exhaustible Resource Cartel: The Case of OPEC," European Economic Review
- Kennedy, M., "An Economic Model of the World Oil Market," Bell Journal of Economic and Management Science 5, (1974):540-577.
- Kuller, R.G. and R.G. Cummings, "An Economic Model of Production and Investment for Petroleum Reservoirs," American Economic Review 64, (1974):66-80.
- Matthews, Steven, "Rate Sensitivity in Petroleum Production and Differences between Monopolistic and Optimal Extraction," October 1975 (xerox).
- Montgomery, W.D., "A Case Study of Regulatory Programs of the FEA," to be published in a Compendium of papers submitted to the Committee on Government Operations, U.S. Senate.
- Nordhaus, W., "The Allocation of Energy Resources," Brookings Papers in Economic Activity 3, (1973):529-576.

- Phelps, Charles E. and Rodney T. Smith, "Petroleum Regulation: The False Dilemma of Decontrol," RAND Corporation Report R-1951-RC, January 1977.
- Roush, Calvin T., "Effects of Federal Price and Allocation Regulations on the Petroleum Industry," Federal Trade Commission, Staff Report R-6-15-33, December 1976.
- Solow, R. and F.Y. Wan, "Extraction Costs in the Theory of Exhaustible Resources," Bell Journal of Economics 7, (1976):59-370.
- Stiglitz, Joseph E., "Growth with Exhaustible Natural Resources: The Competitive Economy," Review of Economic Studies Symposium, (1974):139-152.
- "Report of the Presidential Task Force on Reform of Federal Energy Administration Regulations," Washington, D.C., December 1970.